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International support for feed-in tariffs in developing countries—A review and analysis of proposed mechanisms

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ABSTRACT

Government support in the form of so-called feed-in tariff policies (FITs), which combine long-term, fixed-price electricity purchase agreements and guaranteed grid-access, has attracted large private-sector investments in sustainable electricity generation in the industrialized world. In an effort to replicate these experiences globally, a number of international organizations, NGOs, banks and donor countries are proposing mechanisms to cover part of the cost of FITs in developing countries. This paper reviews these proposals for supported FITs and then uses a case study of Thailand's Alternative Energy Development Plan 2013–2021 to investigate the opportunities and challenges of supporting FITs at a global scale. The review highlights that these proposed mechanisms foresee different roles for national governments and supporting entities, particularly in terms of who is responsible to balance fixed FIT payments with uncertain revenues and savings from carbon markets, donors and avoided fuel consumption. The case study results then show that the uncertainty about the actual cost of supported FITs is so significant that the responsibility to balance the FIT budget has to be considered carefully in the design of any mechanism that is to be employed at scale. To a considerable extent, the uncertainty is driven by the counterfactual analysis, i.e., by assumptions about the future savings from avoided fossil fuel consumption: for example, depending on the fossil fuel price scenario the FIT may result in a cost of USD 17bn or savings of 23bn. Unlike uncertainty about the necessary level of FIT payments, uncertainty about the avoided fossil fuel cost materializes only over the course of the policy's lifetime, making it politically challenging. This suggests that an international support mechanism that differentiates the allocation of responsibility depending on the income-level of the recipient country is more suitable for global-scale support than a one-size-fits-all approach.

Contents

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1. Introduction

Avoiding dangerous climate change will require a rapid upscaling and redirection of electricity infrastructure investments. The Intergovernmental Panel on Climate Change projects that the average annual investment in conventional fossil-fuelled electricity generation over the next 15 years will need to decrease by 20% compared to 2010 levels, while annual investment in low-carbon electricity supply will need to rise to around USD 300bn over the same period, about twice the current level [1]. Trends in overall emission growth indicate that an increasing share of these investments will need to flow into infrastructure in developing countries [2]. How the industrialized world can best support developing countries in attracting these investments is therefore keenly debated among researchers and policymakers [3–10].

Much of the global investment in renewable energy in the last decade has been incentivized by so-called feed-in tariff policies (FITs), which combine long-term, fixed-price electricity purchase agreements and guaranteed grid-access. FITs have been especially successful in attracting private-sector investments in new renewable energy technologies, supporting 64% of global wind and 87% of global PV capacity [8]. The United Nations Development Program estimates that by 2012, 66 countries had some form of FIT in place, up from only two countries in 1990, as shown in Fig. 1 [11]. More than half of these tariffs have been enacted in the developing world, where renewable energy investments reached USD 112bn in 2012, representing some 46% of the world total [12].

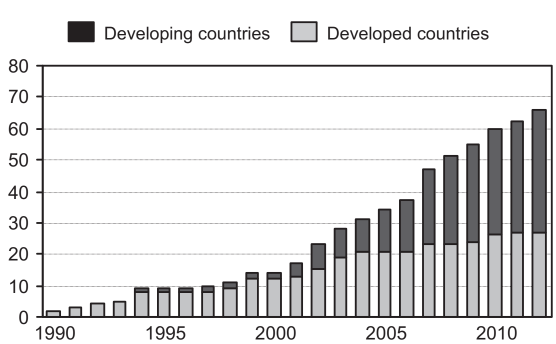

Fig. 1. Number of countries with some form of FIT legislation worldwide, 1990–2012 [11].

The finance flows necessary to alter the trajectory of electricity sector investments in developing countries are significant. The United Nations Department of Economic and Social Affairs (UN DESA) estimates that a large-scale rollout of FITs in developing countries would cost about USD 250–270bn per year [13]. Smaller countries in particular often lack the resources to provide sufficiently stable support to attract private sector investments at a large scale. Most of the current investment in renewable energy in developing countries is thus heavily concentrated, in major markets such as China and India [14]. In an effort to replicate and expand the effects of FITs globally, a number of international organizations, NGOs, banks and donor countries have proposed mechanisms that the international community covers a share of the *incremental cost*,[1] i.e., the cost gap between conventional electricity generation and the FITs in low- and middle-income countries [9,13,15–20].

This paper presents a review and a case study to investigate how FITs in developing countries can be supported internationally. The proposals for "supported FITs" all aim to provide some form of direct international financial transfer to fund FITs in developing countries, but they span a wide range of policy designs, with different administrative forms, responsibilities and tariff structures. Given the size of required commitments, and the long-term nature of payments under FITs, the institutional mechanisms used to allocate and channel international support need to be very well understood before they can be applied on a global scale. However, since most proposals have been formulated in the last four to five years, there has been limited systematic research on supported FITs and how they compare to other forms of international support. For the same reason, there has been little comparative work on the different proposals. To address this gap, this paper first reviews the proposed supported FIT mechanisms, highlighting the ways in which the proposals differ in terms of the roles they assign to the international donors and the national government. In a second step, the paper presents a quantitative case study of a hypothetical internationally supported FIT to finance Thailand's renewable energy targets for 2021 [21]. The case study illustrates the cost and cost determinants of supported FITs, and

[1] In this paper "incremental cost" refers to the difference between conventional and renewable electricity in USD/kWh and is used interchangeably with "cost gap" and "additional cost".

Table 1
Proposed mechanism for internationally supported FITs in developing countries.

Type	Proposal	References/examples	Eligibility	Domestic contribution	Main international support	Institutional structure of support	Who balances FIT budgets?	Further support
Globally managed FITs	FIT support mechanism (FTSM)	Greenpeace; EREC [20]	Countries which fulfil certain policy and income criteria; environmental criteria for projects	Avoided cost (plus possibly carbon credit sales)	Incremental cost (possibly in part through carbon credit purchases)	Global fund	International side	Additional support for infrastructure cost; debt finance
	Global Green New Deal (GGND)	UN DESA [18]	Countries which fulfil income criteria	Avoided cost (plus possibly indicator-based contribution)	(Remaining) incremental cost	Global fund	International side	Additional financial and technical assistance for least developing countries
	Global FIT (GFIT)	DeMartino and Blanc [13]	Countries below electricity consumption threshold, during 2010–2025	Avoided cost (plus possibly additional contribution)	(Remaining) incremental cost	Global fund	International side	Additional financial for least developing countries
	Fossil-fuelled FIT	Proposal for Indonesia FIT Fund [17]	Countries with high share of commodity-type fossil fuels	Avoided cost	Incremental cost (through variable premium based on fossil fuel price development)	Internationally supported fund for each country	International side	NA
Domestically managed supported FITs	FITs with carbon credits under the UNFCCC	Okubo et al. [16] Burian and Arens [28] Edkins et al. [30]	Countries which fulfil certain policy and UNFCCC criteria	Incremental cost minus carbon credit revenues	Carbon credits purchased at market price	Global carbon market	National government	Diverse
	FITs with bilateral carbon credits	Japan's Joint Crediting Mechanism [31]	Based on bilateral agreements	Incremental cost minus carbon credit revenues	Carbon credits purchased at negotiated price	Bilateral carbon market	National government	Technology, assistance in implementation
	Bilateral assistance to national FITs	E.g., Energy+ initiative [27] supports FIT in India	Bilateral decision	Incremental cost minus bilateral transfers	Negotiated bilateral transfers	Bilateral support	National government	Diverse
Globally managed incremen-tal FITs	Global energy transfer FITs (GET FIT)	Deutsche Bank Climate Change Advisors [32,33]; Rickerson et al. [9]	Small-scale plants in countries which fulfil certain policy and income criteria	Fixed tariff representing projected avoided cost (possibly plus domestic contribution)	Fixed premium equal to projected (remaining) incremental cost	Global fund / Supported national funds	National government and international side	Front-loading[a]; debt & equity finance; insurance products; technical assistance
	Green climate fund private sector Ffacility GCF PSF)	Green climate fund business model framework [37]	Small and medium-sized projects in low-income countries	Fixed tariff representing projected avoided cost (possibly plus domestic contribution)	Fixed premium equal to projected (remaining) incremental cost	Global fund	National government and international side	Insurance products
	Global REFIT Facility under the GCF PSF	World future council [15]	Countries which fulfil certain policy and income criteria	Fixed tariff representing projected avoided cost (possibly plus domestic contribution)	Fixed premium equal to projected (remaining) incremental cost	Global fund in cooperation with national funding entities	National government and international side	Additional financial assistance

[a] Front—loading refers to a FIT payment structure under which a certain share of the tariff payments is paid upfront, rather than on an annual basis, to the investor to reduce capital expenditures.

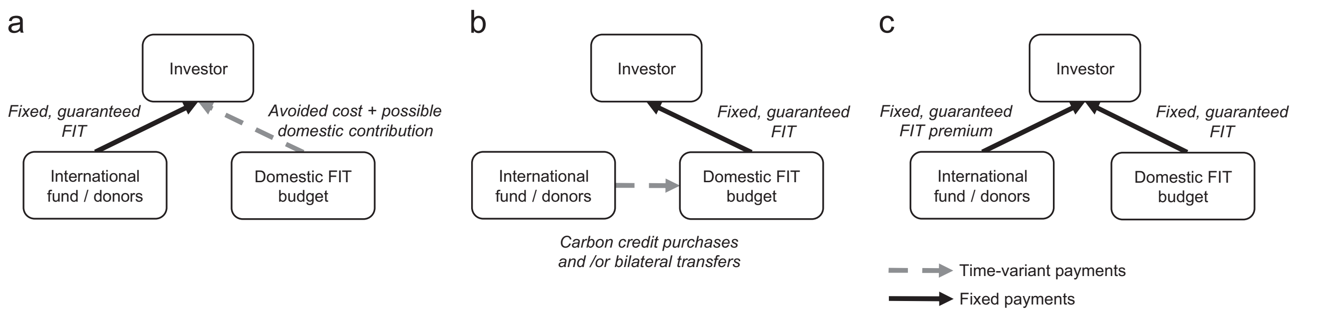

Fig. 2. Payment structure of three alternative types of supported FITs. (a) Globally managed FIT, (b) Supported domestically managed FIT and (c) Globally managed incremental FIT.

suggests that the roles assigned to the international donors and the national government – in particular the responsibility to balance fixed FIT payments with uncertain and volatile revenues and savings – are a crucial design element for internationally supported FITs.

The following section will introduce the different proposals for internationally supported FITs (Section 2). Section 3 introduces the case, followed by Section 4 which presents the model, data sources, and methodology. The results of the case study are presented in Section 5, and their policy implications are discussed in Section 6. The main conclusions of the paper are summarized in Section 7.

2. International support mechanisms for feed-in tariffs in developing countries

2.1. Scope of analysis

This paper defines a FIT in accordance with the World Bank as a performance-based support instrument that offers three key incentives to investors in renewable energy projects: a standardized, fixed electricity purchase tariff per kWh, guaranteed purchase of the electricity produced for a specified period, and guaranteed access to the grid [22]. "Standardized" implies in this case that the available tariff is determined administratively at the moment of project installation and defined by project characteristics, notably installation year, quality of the resource, location, technology and size, rather than individually negotiated or determined by market competition.[2] FITs are generally specified as a regulated purchase obligation on national or regional electric utilities. In addition to the tariffs itself, FIT policies are often complemented by additional incentives in the form of investment grants or low-interest loans [5].

Supported FITs are understood here as mechanisms that aim to *channel international support to directly cover a share of the FIT payments* over the lifetime of the projects. Other means of international support for FITs in developing countries are possible, of course, including technical assistance, grants, loans, financial guarantees, and procedural support, and a number of alternatives to direct FIT coverage have been proposed to support developing countries [4,11,23]. However, these alternatives go beyond the scope of this paper. Furthermore, the presented discussion is limited to FITs for grid-connected policies; proposals for decentralized mini grids supported by FITs are therefore not considered here [24,25].

2.2. Proposed mechanisms to cover FIT cost in developing countries

Existing international funding sources have historically neither been large nor flexible enough to support national FITs in a broad and programmatic way [5]. Aiming to alleviate this situation, the ten main proposals for supported FITs, identified by the author and listed in Tables.

Table 1, can be classified into three categories (see Fig. 2): (1) *globally managed FITs*, which propose global FIT policy regimes that give all developing countries, below certain income or consumption thresholds, the right to opt in to a single, homogenous FIT policy; (2) *domestically managed supported FITs*, which propose ways for heterogeneous, domestically designed and managed FIT policies to access (existing or emerging) international funding sources; and (3) *globally managed incremental FITs*, which propose to upgrade heterogeneous, domestically designed and managed FIT policies through an additional, homogenous global FIT premium, thereby creating, in essence, two parallel FITs which are paid on top of each other.

2.2.1. Globally managed FITs

Three ambitious proposals link global support for FITs to global technology cost or development targets. The European Renewable Energy Council (EREC) and Greenpeace proposed a scheme, called the "FIT Support Mechanism", that aims to bring down the electricity generation cost for all renewable energy technologies to a level below that of conventional coal and gas power plants [20]. Under this proposal, a global fund, financed by indicator-based international contributions, would finance the incremental cost of FITs for a broad range of renewable energy technologies to all developing countries that enact a national FIT law "based on successful examples". Teske et al. [20] estimate that the scheme could cover up to 7400 TWh of annual renewable electricity generation by 2030, corresponding to roughly 37% of the world's total generation in 2010 [26], with incremental cost projected to average USD 60–80bn annually from 2010 to 2030.

A similar program was proposed in 2009 by UN DESA, called the Global Green New Deal [18], through which technology-specific FITs are provided to all developing countries until all supported renewable energy technologies have reached a target cost level of USD 0.03–0.05/kWh. Also under the auspices of UN DESA, DeMartino and Blanc discussed the option to provide a "Global FIT" to all developing countries below a certain electricity consumption threshold. The authors estimate that the cost of reaching this target would peak at around USD 250–270bn (in constant 2010 USD) annually from 2025 to 2030, about twice of the current total development assistance [13]. All three proposals expect income-based contributions by the host countries to the FIT budget, but do not go into detail on how they would be determined.

Although designed initially for a specific country, and without a global goal in mind, the "fossil-fuelled FIT", proposal by Rickerson and Beukering [17] can also be classified as globally managed FIT mechanism if rolled out on a global scale. Developed for the case of Indonesia, the mechanism aims to make FIT support attractive

[2] This definition excludes reverse auctions for purchase tariffs.

for energy import-dependent developing countries through an innovative cost sharing approach. The national government pays the electricity producer a variable electricity tariff that is indexed to the price of fossil fuel imports. This domestic contribution is topped up by an internationally supported fund to provide, in sum, a fixed FIT payment stream. The fund can recover its investment if the domestic contribution exceeds the FIT level long enough, after which the savings are passed through to the ratepayers.

2.2.2. Domestically managed supported FITs

In contrast to the "top-down" approach of the globally managed FITs, a number of proposals focus on how bottom-up, domestically managed FIT policies can get access to broader, existing or emerging international funding structures, notably bilateral development assistance and carbon markets.

Given the nature of performance-based FIT payments, a number of international donors have emphasized that FIT policies are well suited to be supported by result-based, *bilateral development assistance* [5]. The Norwegian government's Energy+ initiative, for example, provides funding to the domestic FIT in India on a bilateral basis [27].

Several other proposals explore the option to receive *carbon credits* for national FIT policies under the emerging post-Kyoto regime for the United Nations Framework Convention on Climate Change (UNFCCC). Central to these ideas is the fact that carbon credits are generated on a sectoral basis rather than a project-by-project basis, possibly easing administrative and transaction cost. For example, Burian and Arens [28], Grant [29] and Edkins et al. [30] consider the possibility of financing FITs in South Africa through sectoral carbon credits. The most detailed elaboration on the topic is provided by Okubo et al. [16], who analyzed South Korea's FIT and suggested that FITs can be supported as a "credited nationally appropriate mitigation action" under the UNFCCC. An alternative is the bilateral carbon market structure that is emerging with Japan's Joint Crediting Mechanism, under which bilateral agreements create a regulatory framework that allows a wide range of carbon emission mitigation initiatives to receive carbon credits. A feasibility study explored how to fund part of the cost of Mongolia's FIT, in addition to technological and financial assistance, in return for the carbon credits generated under the program [31].

2.2.3. Globally managed incremental FITs

Striking a balance between the approaches presented above, *globally managed incremental FITs* aim to build on domestic FITs and support them with a centrally managed FIT support mechanism that draws on established sources and means of development finance.

The GET FIT program, developed by Deutsche Bank for the Advisory Group on Energy and Climate Change of the Secretary General of the United Nations, is the most advanced of these [9,32,33]. It aims to *up-grade* existing national FIT policies through a country-specific combination of up-front payments, performance-based payments, risk insurances and attractive debt finance conditions. The performance-based payments come in the form of a *fixed tariff premium*, which is paid on top of domestic FITs and aims to close the gap between the cost of renewable electricity and the host country's ability to pay. In essence, the GET FIT program creates *a second FIT policy*, with a tariff that reflects the projected cost gap, in addition to the domestic policy. A version of the GET FIT program is currently being tested in Uganda, where GET FIT upgraded the existing FIT in cooperation with the German development bank KfW [34].

Other proposals envision a FIT-specific facility under the Green Climate Fund (GCF), which will manage the annual USD 100bn pledged to be transferred each year to developing countries from 2020 onward under the UNFCCC [15,19,35,36]. The most elaborate scheme, prepared by Michaelowa and Hoch for the World Future Council, calls for the GCF to elicit applications from bottom-up, domestically designed FITs that would be supported by a centrally managed FIT fund. Through this centrally managed fund, the Renewable Energy FIT Facility, the GCF would then subsidize developing countries with an income-dependent share of the cost gap of national FIT policies, in the form of a tariff premium paid on the domestic FIT, together with concessional loans and grants. Under one proposed option, least-developing countries would receive 100% of the projected cost gap between fossil and renewable generation, estimated to range between 2–4 c€/kWh, or 2.76–5.52 cUSD, while medium-income and advanced developed countries would be supported with 50% and 20%, respectively. The authors estimate their proposal to cost USD 1.3bn per year for a program that supports 100 GW of new installations annually [15]. In its recently published business model framework, the GCF itself considers funding incremental FITs for small to medium scale renewables in low and medium income countries as one opportunity for its private sector facility (without going into much further detail) [37].

2.3. Three ways to balance the FIT budget

The most important factors that make FITs an attractive policy for investors in the developed world are stable revenue streams for built projects and predictable FIT levels for new projects [38]. All of the reviewed proposals aim to replicate this stability and certainty for investors in developing countries, and share the fundamental FIT design features. In fact, many of the proposed mechanisms explicitly build on each other. Crucially, however, the three categories of supported FITs differ in how the payments are structured, and how the payment structure in turn shapes the roles of international supporters and the national government (see Fig. 2). In particular, the proposals differ in how the FIT budget is balanced, i.e., how the responsibility to maintain investment security over the full lifetime of the policy is allocated between the developing country government and the international side. "Balancing the FIT budget" is understood here as balancing fixed FIT payments with uncertain and volatile revenues and fuel cost savings to ensure stable income streams for built projects and predictable FIT levels for new investors. The essential question is: which side is covering the uncertainty in the development of incremental cost over time?

Globally managed FIT mechanisms directly guarantee the full required FIT to the investor (see Fig. 2a). The international side thus buffers volatile revenues from carbon credit sales and savings from avoided fossil fuel consumption, and has to adjust its contribution to the incremental cost if projected FIT payments do not match actual revenues and savings. The domestic contribution to the incremental cost, on the other hand, is set ex-ante and by design isolated from any uncertainty about the future development of the incremental cost. EREC and Greenpeace's proposal, for example, suggests that the domestic contribution consists of carbon credit sales and the avoided cost, with the latter being determined according to the "German model". In this model the avoided cost is recovered for the FIT budget by centrally collecting the renewable electricity and selling it on the wholesale market [20].[3] Rickerson and Beukering's [17] proposal directly links the domestic contribution to a fossil-fuel price index. In both cases, the domestic

[3] The UN DESA proposals also assume that developing countries cover the actual avoided cost, although the documents leave open how they would be determined in the case of implementation.

Table 2
Impact of variable revenues and savings on national governments and international donors.

Type	Impact of time-variant donor contributions, carbon credit revenues and avoided cost savings over time on …	
	… international side	… national government
Globally managed FIT mechanisms	Global fund directly guarantees stable FITs and balances uncertain and volatile revenues and savings	No direct impact, but may be required to increase contribution over time
Domestically managed supported FITs	No direct impact, but may be required to increase contribution over time	National government directly guarantees stable FITs and balances uncertain and volatile revenues and savings
Globally managed incremental FITs	Built projects: no direct impact	Built projects: National government balances tariff with uncertain and volatile revenues and savings cost over the project's lifetime
	New projects: global fund could adjust the FIT premium over time	New projects: if global fund does not adjust FIT premiums to changes in incremental cost, the national government would need to raise its payment beyond avoided cost to maintain attractive FIT

Table 3
Impact of incremental cost uncertainty on international and domestic cost under different FIT designs.

Model / scenario	Total incremental cost (USD bn)	Incremental cost covered by international side/domestic side (USD bn)		
		Globally managed FIT, with domestic contribution limited to avoided cost	Domestically managed supported FIT; carbon credits and transfers cover *projected total* incremental cost	Globally managed incremental FIT; international premium covers *projected* incremental cost of *each project*
Standard specification: M_1	21.20	21.20/0.00[a]	21.20/0.00[a]	20.26/0.94[ab]
High investment cost (+20%)	33.07	**33.07**/0.00	21.20/**11.87**	**32.13**/0.94
Low investment cost (−20%)	9.33	**9.33**/0.00	21.20/−**11.87**	**8.39**/0.94
High fuel prices (M_7)	−21.98	−**21.98**/0.00	21.20/−**43.18**	−**21.77**/−**0.21**
Low fuel prices (M_3)	30.78	**30.78**/0.00	21.20/**9.58**	**27.21**/**3.57**

[a] Other initial splits of incremental cost between the national and the international sides are possible, of course, but they do not affect the impact of uncertainty as long as the payment structure and the fundamental principle of uncertainty allocation is maintained.
[b] The domestic contribution is positive because on average the cost of electricity decreases over time, due to learning effects and a decreasing share of displaced build margin.

contribution to the incremental cost is controlled by linking the domestic payments to the *actual* revenues and savings.

Domestically managed supported FITs, in contrast, represent FIT policies in which the national government guarantees the full FIT and is solely responsible for balancing uncertainty in carbon markets as well as donor commitments (Fig. 2b). Under globally managed incremental FITs, finally, the international side provides a *fixed premium* on a *fixed domestic FIT*. Since both tariffs are fixed at the beginning of the policy, neither side absorbs the full incremental cost uncertainty; rather, the cost uncertainty over the lifecycle of *built projects* is absorbed by the national government, while the cost uncertainty for new projects over the lifecycle of *the policy* is absorbed by the international side (Fig. 2c).[4] Table 2 summarizes how variable revenues and savings affect national governments and international donors in different types of supported FITs.

It is important to note that there is no systematic difference between the three types as to how much of the *projected* cost is covered by either side. All contain provisions for the host country to cover the avoided cost, and many foresee some form of local contribution to the incremental cost. The difference is in how volatile and uncertain revenues and savings are buffered and balanced. In fact, the clear boundaries between the three categories would blur in a world with perfect foresight of the future cost of renewable and fossil electricity, carbon price trends and donor commitments. Since these cost and price trends are uncertain, however, and the entity that balances the FIT budget shoulders the risk of unforeseen cost developments, the allocation of budget-balancing responsibility between the international and national sides affects the degree of security that the FIT can provide to investors.

The uncertainty in the incremental cost implies that in order to ensure investment security, the budget-balancing responsibility has to be allocated in a way that reflects each side's political and financial capital to support the FIT. It also implies that the degree of uncertainty about the actual incremental cost is as important for the political feasibility of the policy as the overall magnitude of involved commitments. The quantitative case study presented in the following sections therefore explores both the overall magnitude of the incremental cost and the impact of cost uncertainty on the national and international sides under the three different supported-FIT designs.

3. Thailand's alternative energy development plan

3.1. Electricity sector background

This paper presents a quantitative case study of Thailand's electricity sector, which assumes that the country's renewable energy targets for 2021, specified in the Alternative Energy

[4] Deutsche Bank's GET FIT and the GCF proposal [81] each contain provisions to insure the domestic contribution against a default. However, the international contribution is under normal circumstances limited to the fixed premium, while the national government's contribution varies over the lifecycle of the projects with volatile fossil fuel prices.

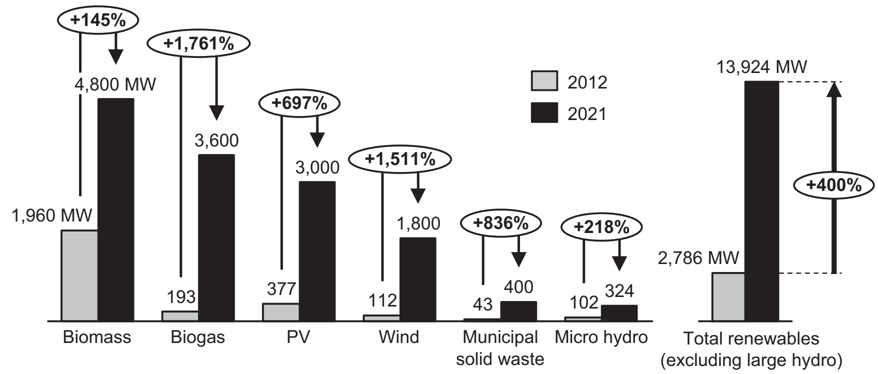

Fig. 3. Targets for renewable electricity under Thailand's Alternative Energy Development Plan; data for 2012 are from DEDE [64]; updated targets for 2021 from Kamolpanus [44].

Development Plan (AEDP) [21], are achieved with the help of an internationally supported FIT.

Thailand was chosen as case study because its electricity sector is representative of many middle-income countries in three significant ways. First, the country's electricity is mainly produced from fossil fuels. As of 2011, the electricity sector is dominated by natural gas (67%), with lignite and hard coal providing together an additional 20%. Besides large hydropower (5%), renewable energy constitutes only a small fraction of the electricity mix, mostly in the form of biomass (1.4%) [39]. Second, the country is witnessing a rapid growth in energy demand. A country of 66.9 million with a GDP per capita at USD 5210, Thailand's primary energy consumption has almost tripled from 1990 to 2011, making it the second-largest energy consumer in the Association of Southeast Asian Nations (ASEAN), while its carbon emissions have grown by 177.5% over the same period.[5] Electricity generation reached 162 TWh in 2011, up from 29 TWh in 1987, and is projected to double yet again by 2035 [39–41]. Third, like many other middle-income countries, Thailand is increasingly dependent on fossil fuel imports. The country is a net importer of oil, gas and coal, with imports projected to increase to about 90% of consumed oil and gas by 2030 [41]. Nakawiro et al. [42] estimate that gas and coal import cost will rise as share of GDP from 0.92% in 2011 to 2.19–2.69% in 2025, depending on the development of fuel prices in the region.

All three factors have particular implications for the calculation of the incremental cost of renewable energy, and are thus relevant to the potential of the case study's results to inform a possible global application of internationally supported FITs. The dependence on fossil fuels makes the savings from avoided fossil fuel consumption the most important factor in the calculation of avoided cost, while rapid demand growth introduces uncertainty into the calculation of avoided cost of conventional generation, because assumptions have to be made about the impact of renewable energy diffusion on the construction of new fossil fuel power plants. Lastly, import dependence implies that the avoided costs are determined by international energy commodity prices, which tend to be more volatile than domestic fossil fuel sources, especially lignite and natural gas.

3.2. Renewable energy targets and current policy support

An additional reason to select Thailand as a case study for a supported FIT is that the country has ambitious goals for renewable electricity, but still faces challenges in providing an integrated, stable regulatory framework to achieve these targets [43].

Thailand's electricity sector planning officials have begun to consider renewable energy as a significant source of electricity generation. The country first formulated its ambitious renewable energy goals in the AEDP of 2012. Updated in 2013 and now aiming to increase the renewable energy in the power sector to 14 GW by 2021, or 24% of the total capacity, the plan is expected to be integrated in the country's overall electricity sector plan over the course of 2014 [44,45]. As shown in Fig. 3, the largest part of renewable capacity is projected to come from biomass (4.8 GW), followed by biogas (3.6 GW), solar power (3 GW), wind power (1.8 GW), municipal solid waste (400 MW) and micro hydro (324 MW). The largest relative increase is targeted for biogas (17-fold) and wind energy (15-fold). It is notable that large hydro is not part of the AEDP. For simplification, we therefore use the term 'renewable electricity' in this paper to refer to non-large-hydro renewable electricity technologies.

The policies and regulatory framework to support these ambitious targets are still in flux. In addition to tax incentives and investment grants, the primary government policy to induce renewable energy investments is a FIT premium scheme, referred to as *FIT adder*, under which technology-specific premiums are paid on top of the (variable) wholesale electricity price [43,46]. One of the first developing countries to introduce a FIT program, Thailand implemented preferential grid-connection and avoided-cost tariffs in 2002, followed by technology-specific FIT premiums in 2006 [43]. The FIT adder program offers investors a power purchase agreement under which fixed premiums, dependent on technology, capacity and project location, are paid on top of a base tariff that is determined by the utility's avoided cost. The FIT adder has been quite successful in attracting private sector investment, but has experienced cycles of boom and bust of applications, fuelled in part by speculation on the value of land with issued licenses for renewable installations [43]. A significant share of issued solar licenses has since been revoked [47]. In 2010, Thailand's government announced plans to transform the FIT adder into a FIT with fixed payments, but has done it so far only for rooftop solar PV [44].

4. Methodology

4.1. Framework of analysis

A two-step methodology was employed to investigate the overall magnitude of the incremental cost of the AEDP targets and the impact of incremental cost uncertainty on the national and international sides under the three different supported-FIT designs.

First, a bottom-up, techno-economic model was developed to identify the incremental policy cost and the main cost drivers (details in Sections 4.2 and 4.3). The model focuses on six

[5] The power sector is the largest carbon source, with a share in national emissions that grew from 33% in 1990 to 42% in 2011.

renewable energy technologies: biomass, biogas, micro-hydro, onshore wind, solar PV, and concentrating solar power (CSP).[6] Fig. A1 in Appendix A depicts the overall structure of the model with its key variables and relationships. Two main model outcome metrics are used to assess the policy support needed to achieve Thailand's renewable electricity targets: the *incremental policy cost* as a proxy for marginal social cost [48,49], calculated as cumulative difference between the total cost of renewable electricity generation and the cost of avoided fossil electricity; and the *abatement cost*, i.e., the incremental cost divided by the reduction of carbon emissions resulting from the AEDP.

The impact of different policy design options was then analyzed in a second step by estimating the changes to cost commitments from the national and the international side under different cost trends and assumptions. To gauge the uncertainty about the level of required *FIT payments* a sensitivity analysis was used (all major input values were varied by $\pm 20\%$). The uncertainty about the *avoided cost* was estimated using different counterfactual scenarios in the form of alternative fossil fuel price assumptions, fossil fuel price trends and methodologies to calculate the avoided cost (see Section 4.4).

4.2. Cost of FIT payments

The electricity generated by each source of renewable electricity is a function of the diffusion path (in GW installed each year) and the plant utilization (in GWh produced per GW of installed capacity each year). Since the AEDP does not contain interim targets, the diffusion of the six considered technologies was modeled as a linear increase in installed capacity over the period 2013–2021.[7] All renewable electricity is assumed to be fed into the grid, so the plant utilization is a function only of the resource potential. In the case of micro hydro, biogas and biomass, for which significant domestic experience exists, the capacity values were taken from domestic academic sources [50–52]. For wind, solar PV and CSP the capacity factors were estimated using resource information from the IRENA global atlas [53].

To model the FIT payments per unit of electricity produced, it was assumed that the government supports each investment with an inflation-adjusted FIT over 20 years, resulting in FIT payments over the period 2013–2040 for the investments in 2013–2021. The FIT rates for each technology are assumed to exactly reflect the technology's LCOE, or levelized cost of electricity for investments at any point between 2013 and 2021 [23]. An additional 0.0115 USD/kWh were added to the LCOE to account for balancing and grid integration cost of variable renewable energy technologies (PV, CSP and wind) [54]. Tables A1 and A4 in Appendix A provide an overview of input parameters used to calculate the LCOE for the six renewable energy technologies as well as key sector-wide assumptions used in the model.

4.3. Avoided cost

To model the effect of renewable energy diffusion on conventional electricity generation, we compared the hypothetical scenario without renewable energy diffusion to the case of full implementation of the AEDP targets. The total avoided conventional electricity was then calculated by aggregating the differences between total generation in 2013–2040 with and without AEDP targets for each of the dispatchable technologies (generation from non-dispatachable technologies is not affected by the AEDP).

4.3.1. Fuel-mix model

Thailand's electricity sector is partly vertically integrated and dominated by state-owned enterprises [55]. The Electricity Generation Authority of Thailand is the transmission system operator, but also operates around 50% of the generation assets directly and controls, as their largest shareholder, the two largest independent power producers. Furthermore, the wholesale market is not liberalized. Decisions over new power plant investments are therefore still made based on long-term integrated plans, rather than purely based on market signals, and plant utilization is based on long-term allocations rather than marginal cost of generation.

The model aims to capture this decision-making process when calculating the fuel mix. The power plant pipeline was taken from the current Power Development Plan (PDP), published in June 2012 [40]. The model builds additional power plants in the sequence determined by the PDP whenever dependable capacity does not exceed peak demand by at least 15%, reflecting the reserve margin required by electricity sector planners [40], or total expected demand exceeds expected generation, based on historic capacity factors, by more than 5%. An exception was made for all hydro power, combined-heat-and-power, and contracted import capacity, which were assumed to come online as planned. This approach is similar to the one adopted by domestic researchers [56]. The dependable capacity equals the total capacity adjusted by factors that aim to reflect the fact that not all built capacity can be expected to be available in the moment of peak demand, because of maintenance, failures, or intermittent generation.[8] The fuel mix was then calculated, on a yearly basis, from historic capacity factors, marginally adjusted for the dispatchable plant fleet to exactly meet yearly demand. 'Dispatchable' here refers to the plants that are ramped up and down to balance demand, i.e., the full fleet excluding renewables, contracted import capacity (lignite and hydro), municipal solid waste and (heat-led) cogeneration.

4.3.2. The cost of avoided electricity

Modeling the marginal cost of avoided electricity required differentiating the impact of renewable capacity installations on fossil generation capacity. This impact can be twofold: plant utilization of dispatchable power plants can be reduced, or the construction of new power plants postponed. The model accounted for these two effects by dividing the total avoided electricity into *operating margin* and *build margin*. For all displaced electricity, the cost of electricity was calculated as LCOE. However, in the case of reduced plant utilization, the *operating margin*, we assumed the marginal cost of electricity to contain only the variable cost (O&M and fuel). The displaced electricity from postponed power plants, the *build margin*, contains all fixed and variable cost.[9] All input assumptions for the conventional electricity LCOE calculations are summarized in Table A2 in Appendix A.

4.4. Avoided cost scenarios

In total, 11 models were specified to analyze uncertainty in the avoided cost. Nine models estimate the impact of different assumptions about fossil fuel prices and price trends (M_{1-9}). These nine specifications represent the combination of three different assumptions about the *price per unit of avoided natural gas consumption* and three different *fossil fuel price trends* (3×3 price scenarios). When making assumptions about the price of natural

[6] Municipal solid waste was not considered because of a lack of data on technology choice and cost in Thailand.

[7] The split between PV and CSP in the (un-differentiated) total solar target is assumed as a relation of 9: (PV) to 1 (CSP).

[8] The factors were taken from Sangarasri-Greacen and Greacen [56] and Naksrisuk and Audomvongseree [68].

[9] This procedure was also employed by Schmidt et al. [48] and is related to the rules employed to calculate avoided carbon emissions in the Clean Development Mechanism under the UNFCCC.

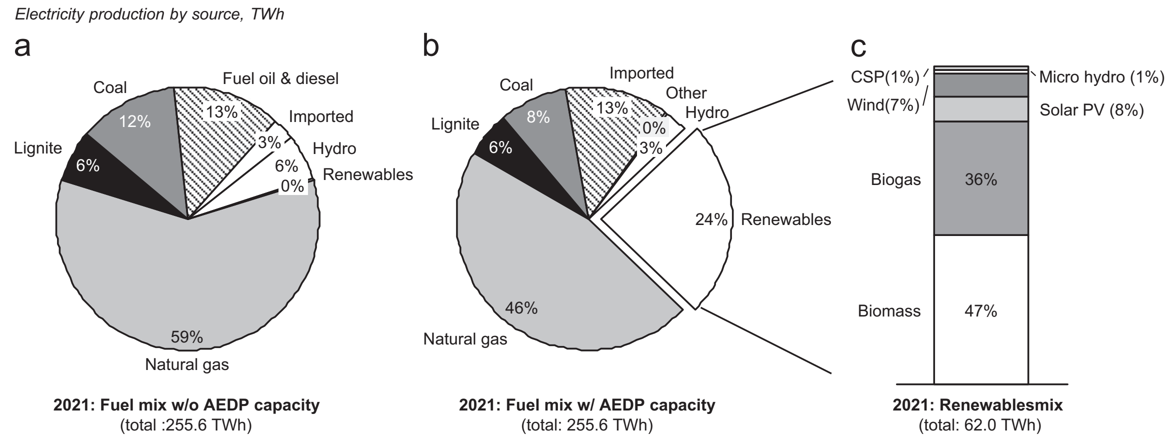

Fig. 4. Change in fuel mix through the AEDP: (a) fuel mix in 2021 without any new renewable installations after 2012; (b) fuel mix in 2021 with AEDP targets; (c) shows the renewable generation in 2021 with the AEDP targets in detail.

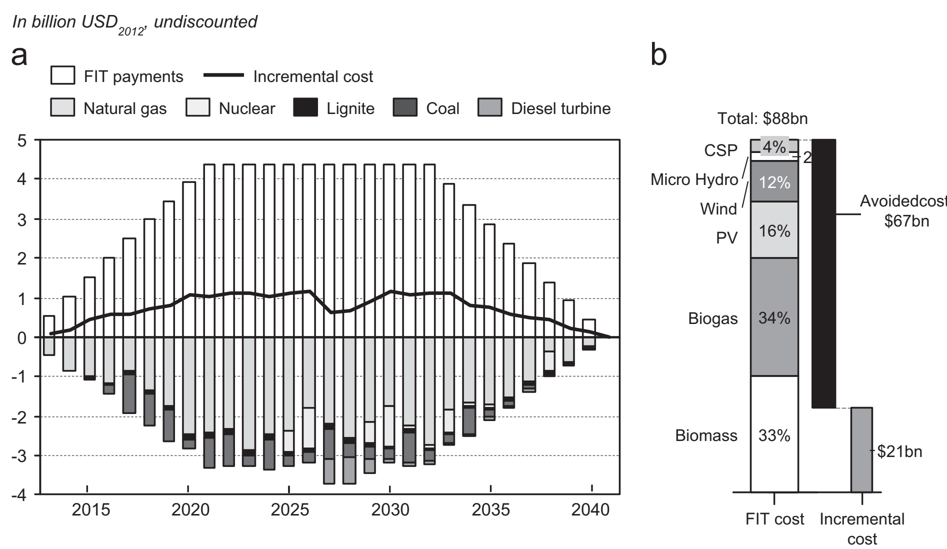

Fig. 5. (a) Assumed FIT payments (positive), avoided cost (negative) and resulting incremental cost under the AEDP 2013–2040; (b) total FIT cost, avoided cost and incremental cost, 2013–2040.

gas in the displaced electricity, it is important to note that natural gas in Thailand, as in the rest of the world, is not priced uniformly.[10] *Which type* of natural gas is displaced by renewables therefore greatly affects the incremental cost. To analyze this effect, models were calculated using the average price, the average import price, and the average LNG import price. The three fossil fuel price trends were taken from the International Energy Agency [57]. The two remaining specifications, M_{10-11}, estimated the impact of two alternative assumptions on the degree to which renewables delay new fossil power plants. The standard specification assumes that the displaced electricity is a mix of operating and build margin (see Section 4.3.2). Greenpeace's proposal [20], however, determines the avoided cost using the German model, i.e., through wholesale electricity prices, which typically only reflects operating cost. This implies that all displaced electricity is calculated as operating margin. The opposite assumption is made in the proposal by UN DESA [13], which assumes that all displaced electricity would have to come from new power plants – and therefore contains both capital and operating cost. Models M_{10-11} estimate the impact of these alternative assumptions.

5. Results

5.1. Incremental cost of and cost drivers of FIT policy

The AEDP capacity targets will, if implemented as planned, lead to a significant transformation of Thailand's electricity sector. The model predicts that the new capacity installed under the AEDP will increase the share of renewable energy generation, excluding large hydro, in the electricity mix from less than 1% to 24% in 2021 (see Fig. 4). Over the entire policy lifetime, the AEDP will reduce carbon emissions by some 457 million tons CO_{2eq}.

FIT payments of USD 87.66bn, or 68.34bn in discounted terms,[11] are needed to finance this rise in renewable electricity generation. This translates into an abatement cost of USD 36 per

[10] The average price overall is about 7 USD/MBTU, the average import price about 8.4 USD/MBTU and the average price of imported liquefied natural gas (LNG) about 14.6 USD/MBTU [78].

[11] Discounted to the year 2012 with the yield of 40-year Thai government bonds (4.43%), which reflects the refinancing cost of the Thai government over the period of the assumed FIT payments.

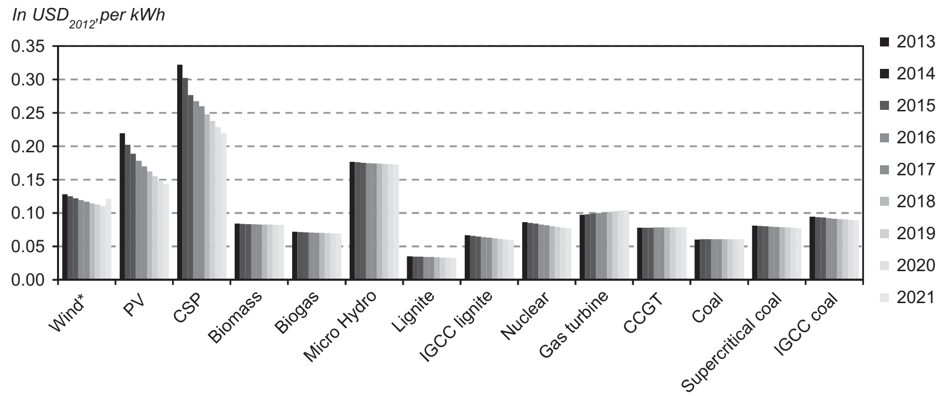

Fig. 6. Trends in LCOE for six modeled renewable energy technologies and main fossil fuel alternatives 2013–2021 (avoided cost scenario specification: M_1); * the reason for the increase in wind LCOE in 2021 is that the best wind resources will be exhausted by then.

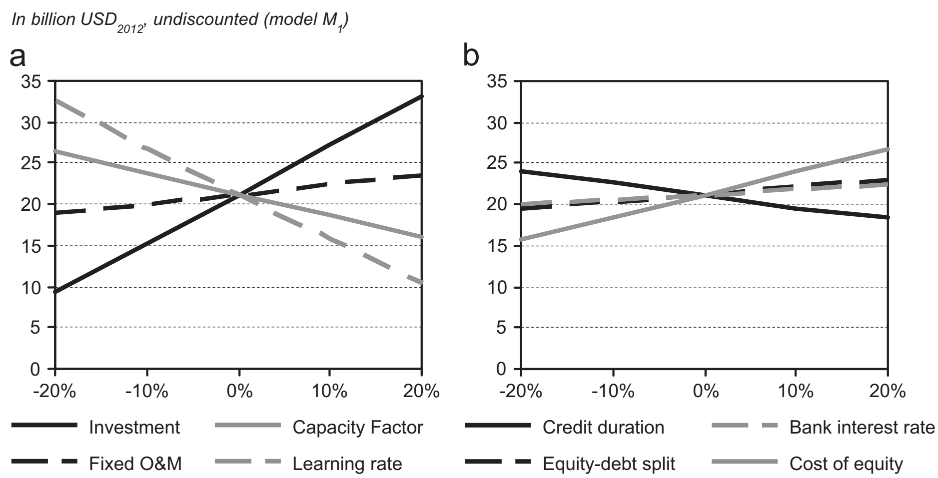

Fig. 7. Sensitivity of incremental cost to renewable energy input parameters.

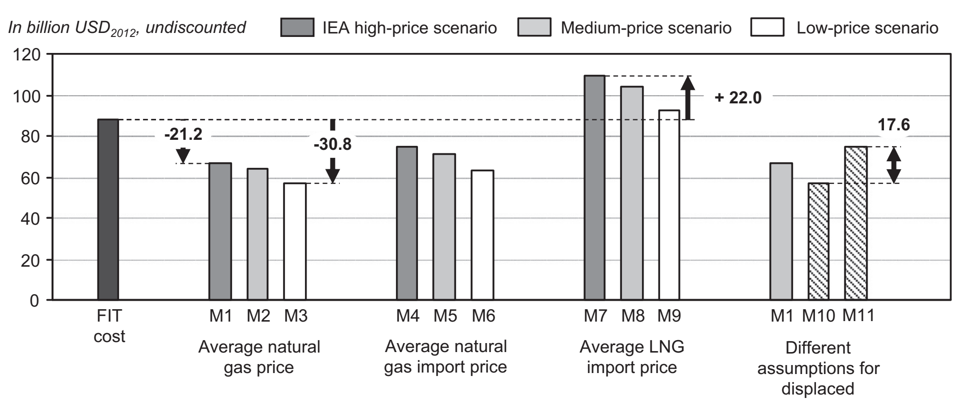

Fig. 8. Avoided and incremental cost in different fossil-fuel cost scenarios.

ton of CO_{2eq} in discounted USD_{2012}. The payment streams for all technologies for the period 2013–2040 are displayed in Fig. 5, together with the avoided cost over the same period. Aggregated over all six renewable technologies, FIT payments rise linearly to USD 4.38bn in 2021 and stay stable until 2032, before falling to zero in 2041, when the last plant installed under the FIT goes offline. The avoided cost is USD 66.46bn, or 51.84bn in present value. Over time, the avoided cost follows a similar path, with some volatility, reaching a maximum of USD 3.74bn in 2027 in the standard model specification M_1. Subtracting these from the FIT cost leaves an incremental cost of USD 21.20bn (discounted: 16.50bn). The incremental cost peaks at USD 1.18bn in 2026 and remain positive over the entire policy lifetime. On average, the FIT policy costs an additional USD 0.76bn per year, which corresponds to an average incremental cost of cUSD 2.2 per kWh of renewable electricity.

The LCOE by technology are displayed in Fig. 6 for the period 2013–2021. Benefiting from global learning effects, the costs of all

renewable technologies decrease over time. The decrease is strongest for CSP (35%) and PV (32%) and weakest for biomass (2%). Nevertheless, CSP, PV, wind and micro hydro are more expensive than the main fossil technologies and remain so until 2021. Biomass and biogas are in the same range as most fossil fuel technologies, costing 8.2 cUSD/kWh and 6.9 cUSD/kWh in 2021, with only subcritical lignite and subcritical coal power plants being significantly cheaper. These LCOE trends are reflected in each technology's contribution to the FIT cost. As shown in Fig. 4, biomass and biogas together account for 83% of renewable generation, but only 67% of the FIT payments (see Fig. 5). PV and wind are responsible for 8% and 7% of generation, respectively, while receiving 16% and 12% of the payments. CSP and micro hydro also receive a significantly larger share of FIT payments (4% and 2%) than they contribute to generation (1% each).

As can be seen when comparing Fig. 4a and b, the additional renewable generation displaces mostly coal (−4%) and natural gas (−13%). The avoided costs thus comes primarily from avoided natural gas consumption (71% of avoided cost), followed by coal with 16% and nuclear with 7%. This illustrates that the chosen mix of renewable energy and the type of displaced electricity are the most important drivers of the incremental cost.

5.2. Uncertainty of incremental cost

This section explores how sensitive the incremental cost calculations presented above are to input assumptions. The results for FIT payments, avoided cost and incremental cost in section 5.1 are based on the baseline model specification M_1, which assumes standard assumptions for renewable energy cost, average natural gas prices, IEA's "current policy" fuel trends, and a mix of operating and build margin in the avoided cost. Fig. 7 shows the impact of changes in renewable cost assumptions, while Fig. 8 displays results for the different avoided cost scenarios.

The results suggest that the incremental cost is most strongly affected by changes in the investment cost of renewable technologies (2.8% change in incremental cost per 1% change of diffusion) and the learning rate (2.7%). Although smaller in magnitude, the incremental cost is also sensitive to the capacity factor (1.2%) and the cost of equity (1.3%; shown in Fig. 7b). The incremental cost is less sensitive to changes in the fixed operation and maintenance (O&M) cost, bank interest rate, debt-equity split and the credit duration.

As shown in Fig. 8, the differences between avoided cost scenarios have an even stronger impact than the renewable cost parameters. If it is assumed that the displaced natural gas consumption is priced at the average natural gas price (model M_1), the avoided cost are USD 66.46bn; if it assumed that imported natural gas is displaced first (M_4), the avoided cost reach USD 74.51bn, which reduces the incremental cost by 38% to USD 13.15bn. If it is assumed that the avoided electricity would have been fueled by liquefied natural gas (M_7), the avoided cost rise to USD 109.64bn, which translates into *negative incremental cost*, or savings, of USD 21.98bn. Although weaker, the different fuel price trend scenarios also have an impact on the incremental cost, as shown for M_{2-3}, M_{5-6}, and M_{8-9}. The difference between the high and low fossil-fuel price scenarios of the IEA is about USD 9bn, corresponding to about 45% of the incremental cost in the standard model specification, and roughly constant across the three sets of models. Finally, the impact of the assumption whether new or existing power plants are displaced, modeled in M_8 and M_{11}, can change the incremental cost by as much as USD 17.6bn. Overall, these results imply that the uncertainty about the incremental cost is driven, to a large extent, by the counterfactual, i.e., by the questions which fossil fuels are displaced, from which type of plants, and at what price.

5.3. Impact of uncertainty under different supported-FIT designs

The different types of supported-FIT designs allocate the cost uncertainty differently between the national and the international side. Table 3 shows the share of incremental cost covered by each side under the three alternative supported-FIT designs when investment costs are varied by ±20% and fuel prices follow the two extreme scenarios M_7 and M_3.

Under a *globally managed FIT* the international side would cover all changes in incremental cost. If the domestic contribution is limited to the real avoided cost, the international contribution in the four considered cases would range between savings of USD 21.98bn and a cost of 30.78bn. Under a *domestically managed supported FIT* that receives international funds from the carbon market and/or pre-negotiated bilateral transfers, the four scenarios would, ceteris paribus, lead to changes in domestic costs ranging between a savings of 43.18bn and cost of 11.87bn (for purposes of simplification, the international contribution is assumed here to cover exactly the projected total incremental cost[12]). In the case of a *globally managed incremental FIT*, both sides are affected by the uncertainty. If each project receives a FIT equaling the current average avoided cost from the domestic government and the remaining gap to the LCOE as a FIT premium from the international side, the cost coverage in the standard specification would be USD 20.26bn and 0.94bn, with variation from −21.77bn to 32.13bn and −0.21bn to 3.57bn, respectively.

6. Discussion

The following discussion is split into two parts. The first part discusses the results of the quantitative case study and puts the numbers into perspective (Section 6.1). The second part explores the policy implications of the paper's results, including the findings from the review of proposals in Section 2 and the quantitative case results in Section 5 (Section 6.2). The section closes with a discussion of the paper's limitations (Section 6.3).

It has to be noted that the following discussion is limited to FITs as a policy option and does not discuss in detail the relative merits of FITs compared to other policy instruments aimed at promoting emission reductions in general, or low-carbon electricity in particular.

6.1. Incremental cost of supported FITs

6.1.1. Magnitude of incremental FIT cost

The case study of Thailand's AEDP yields similar results to the global estimates of the incremental cost of supported FITs [13,15,20]. At an average of cUSD 2.2 per kWh over the period 2013–2040 in the standard model specification, the incremental cost of Thailand's AEDP targets are in the cost range of estimates such as the c€ 2–4 per kWh calculated by Michaelowa and Hoch [15] and the premiums of cUSD 1–2 per kWh paid by the GET FIT pilot in Uganda [34].

The mitigation cost of USD 36 per ton of CO_{2eq} is slightly higher than the 23.1 calculated by Teske et al. [20] but, again, in the same order of magnitude. It is also more than the value of the carbon credits yielded under the Clean Development Mechanism, even when their price peaked in 2008, which means that it is highly unlikely that carbon credits under the current international

[12] If the carbon credits are sold on a carbon market, the carbon price creates an additional source of uncertainty in the incremental cost. This uncertainty is not explored in more detail here but needs to be considered by policymakers.

climate policy regime would be sufficient to fully cover the incremental cost of a supported FIT.

When the results for the Thailand case are extrapolated to all non-OECD countries, supporting the same share of total electricity generation (24%) in 2021 across the Global South would cost some USD 80bn per year, which is in the same order of magnitude as estimates by the European Renewable Energy Council and Greenpeace (although they assume a higher share of supported generation) [20]. Notably, this figure is in the same range as the *total* global official development assistance flows of USD 127bn in 2010 [58]. Given these large funding needs, any proposed mechanism to allocate and guarantee national and international commitments must pay great attention to minimizing cost and uncertainty.

6.1.2. Uncertainty in incremental cost

The uncertainty in incremental FIT cost consists of two parts that must be discussed separately. Existing studies have focused on the uncertainty about the level of FIT payments required to attract a given amount of renewable capacity [13].[13] In the case of Thailand, this uncertainty is driven largely by the investment cost, learning rate, capacity factor and cost of equity. Although significant, uncertainty about the FIT payments does not affect the commitments ex-post; rather, it is resolved in the moment of investment, because the FIT rates are fixed for the full lifetime of the project. (Uncertainty in the O&M cost, which was also identified as an important factor in the sensitivity analysis, is shouldered by the investor). This part of the incremental cost uncertainty can therefore be resolved and managed with the existing FIT policy design toolbox: feasibility studies, pilot FIT projects or regions, expert elicitations, and frequent rate-setting reviews [5]. It does put the overall targets of the policy at risk because escalating incremental cost might jeopardize political legitimacy in the long run, but the impact on short-term investment security is likely to be limited.

More difficult to manage, and potentially larger in magnitude, is the uncertainty about the avoided fossil fuel consumption. In the case of Thailand, the impact of different avoided cost scenarios in fact dwarfs the uncertainty about renewable energy cost: between the nine main marginal fuel price scenarios, the incremental cost varied between negative USD 22bn and positive USD 30bn—and none of the scenarios seem entirely implausible. This range of cost corresponds to −4.7% and +4.5% of Thailand's GDP in 2012 [59], which compares to the total government tax revenue in 2013 of about 16.5% of GDP [59].

6.2. Policy implications

The quantitative case study results suggest that the incremental cost of renewable electricity in developing countries is still substantial. Any supported FIT therefore needs to be designed with all major cost drivers in mind in order to minimize necessary financial assistance. The model results suggest that the incremental FIT cost is largely determined by (1) the growth rate of different renewable energy sources, (2) the FIT rates for each technology and (3) the displaced electricity sources. The policy implications of these drivers will be discussed in detail in Section 6.2.1.

Furthermore, the review of proposals in Section 2 highlighted that the proposals differ in how they allocate the uncertainty of the avoided cost. In view of its magnitude, highlighted by the quantitative case study, allocating the uncertainty in incremental cost becomes a major challenge in the design of supported FITs. The implications of this finding for policymakers are discussed in Section 6.2.2.

6.2.1. Containing the incremental FIT cost

6.2.1.1. Resources and capacity growth rates. When managing the growth rate of different renewable energy sources, donors and national governments should aim to ensure that the best resources and most appropriate technologies are exploited first. Unlike other policy options such as emission trading or technology-neutral reverse auctions, FITs are not designed to prefer the cheapest technology—on the contrary, their success in bringing down costs of technologies such as PV is based on the fact that they allow for experimentation, learning and economies of scale in technologies that cannot yet compete with established technologies.

Any supported FIT therefore needs to be accompanied by capacity building activities to enhance the local policymakers' and regulators' understanding of the resource potentials of different renewable energy sources and the cost of state-of-the-art technology. Initiatives such as the IRENA Cost Database and the Global Atlas of renewable resources [53] are very important steps in that direction, as are the numerous initiatives going on in the realm of bilateral development cooperation.

Besides technical aspects, international policy learning and the exchange of legislative experience are needed, too. Some developed countries, notably Germany and Spain, have had problems containing the overall cost of their FIT policies because there were no limit to how much of each renewable technology can be installed at any given time, and tariff rates at times did not reflect the actual cost of renewables. Given that developing countries are less well positioned to shoulder unexpected cost overruns, international collaboration is needed to ensure that supported FITs avoid pitfalls that might jeopardize their long-term political legitimacy.

6.2.1.2. FIT rates. To ensure that rates are set appropriately, a supported FIT needs to be administered through a carefully designed application, review and licensing process. If the rates are set by the regulator, they should be subject to regular review and revision. Some emerging economies have successfully linked FIT policies to reverse auctions, a measure that could be used to manage both the FIT rates and the cost of new commitments [81]. The Green Climate Fund has also considered this option [37]. In a supported FIT, reverse auctions could be implemented in a two-staged model, with national designated entities applying for batches of FIT projects at fixed rates to the international fund and investors applying to the designated national entity for the individual projects.

6.2.1.3. The cost of avoided electricity. The third factor – in which fossil fuel sources are displaced by renewable electricity – is at least as important for the incremental cost as the first two factors discussed above, but often neglected in FIT cost analyses [48]. The case study showed that the avoided costs cover a very significant share of the total FIT cost (USD 67bn of the total 88bn, or 76%). What type of electricity is displaced and how its price is determined therefore affects the cost-effectiveness of a supported FIT and its political feasibility. As such, a supported FIT design should aim to fulfill two requirements with regard to the avoided cost.

The first requirement is that the *most expensive fossil fuel is displaced first*. In many countries, including Thailand, the decommissioning of power plants is not always based on marginal cost, but a complex outcome of contractual and political arrangements.

[13] Although not explicitly considered here, the uncertainty about how much capacity investment can actually be attracted per year also falls into the 'ex-ante' category of uncertainty.

Which electricity is displaced is therefore not always determined by costs alone. Supported FITs should either be designed ex-ante to only cover the cost gap to the most expensive fossil technology in use or – if the international contribution is determined ex-post, as in some of the proposed mechanisms – require that plant decommissioning is cost-based.[14]

The second requirement is that the *full avoided fossil electricity cost* provide the basis for calculating the incremental FIT cost. In the case of small quantities of renewable electricity, the avoided cost equals the marginal cost of electricity, which is roughly equal to the *fuel cost* in the case of most fossil fuel powered electricity. Whenever large quantities of renewable electricity are supported, however, the *capital cost* of avoided new fossil power plants needs to be considered in the avoided cost calculations, too. This is inherently difficult because it is based on counterfactuals – i.e. what would have been built without the renewable installations. Developed countries have some experience with determining capacity credits of renewable installations e.g., [60] and should assist developing countries in designing mechanisms to account for capital cost in the avoided cost of renewable installations.

6.2.2. Allocating the uncertainty in the avoided cost

The quantitative case study illustrated how the three different types of supported FITs differ in the way they allocate the avoided-cost uncertainty between the national and the international side. It also illustrated that the uncertainty within the avoided cost is so large that it may jeopardize the ability of the FIT to attract private sector investment. The choice between the three types of supported FITs therefore critically affects the ability of a supported FIT to achieve its targets.

If the avoided cost is absorbed by the national government, as under *domestically managed supported FITs*, the policy may become unsustainable domestically, as recent experience in Europe suggests. In the long run, surging incremental costs may delegitimize support for new projects and lead to policy changes, as happened in Germany [61,62]. New investments become less attractive or even unprofitable, potentially compromising long-term diffusion targets. In the short term, political legitimacy may also diminish so far that FIT revenues are changed or taxed retroactively, as with Spain and The Czech Republic, the value of existing renewable generation assets plummets immediately. Both scenarios put the policy's long-term targets at risk. What's more, since the investors' cost of capital is affected by their and the lenders' degree of trust in the ability of the budget-balancing entity to deliver on its promise over the entire life-time of the project, even the *prospect* of either scenario may inhibit the FIT from attaining its targets cost-effectively. In addition, reducing the dependence on volatile fossil fuel prices is a major motivation for developing countries to invest in renewables [63]—requiring the host country to balance this volatile avoided cost would re-introduce the dependence on fuel prices and could therefore remove most incentives to invest in the first place. On the other hand, assigning this uncertainty to the international side, as done by the *globally managed FITs*, renders credible long-term commitments politically difficult, and very large bilateral commitments probably infeasible.

It seems unrealistic that one solution to this conundrum can satisfy all combinations of donor and host countries. For least-developed countries it might be necessary for international donors to absorb the full avoided cost risk by guaranteeing the full FIT payments (as proposed by *globally managed FITs*), whereas *domestically managed supported FITs* could be more appropriate for upper middle-income countries, because they can be expected to shoulder most of the avoided cost risks of the FIT policies. Sharing the uncertainty between the national and international side, as done by *globally managed incremental FITs*, could be a suitable approach for the many developing countries that lie in between the two extremes. For the design of a globally applicable mechanism, differentiating the budget-balancing responsibility depending on the income-level of the recipient country and other characteristics such as the existing fuel mix, thus might be more promising than a one-size-fits all approach.

6.3. Limitations

A techno-economic model such as the one presented here can provide quantitative estimates for the investigated variables, but also has inherent limitations. Thus, three main factors need to be emphasized. First and foremost, although the model's assumption aimed to reflect the economics of projects in Thailand by using local sources whenever possible, all absolute model results are to be taken with a grain of salt. Investment cost parameters for renewable and fossil generation in particular varied by two-digit percentages between reviewed studies and are thus particularly subject to uncertainty. A second important limitation is that this paper employed sensitivity and scenario analyses because it was impossible to obtain probabilities for different cost parameters or trends. However, the real policy cost uncertainty is a function of *probabilities* in addition to *sensitivities*. Better models to estimate the uncertainty of the policy cost need to be built before any of the proposed mechanisms can be rolled out on a large scale. Thirdly, the model assumed that all FIT payments are made in USD and neglected the currency risk, which could be a significant barrier for developing countries when providing USD tariffs [7]. How the currency risk is treated by different supported FIT proposals and how significant it is compared to other drivers of uncertainty should be the subject of further research.

The presented case study can thus only provide one additional step toward a better understanding of the economics of renewable energy in developing countries and international support mechanisms.

7. Conclusion

This paper investigated how feed-in tariffs (FITs) in developing countries can be supported through direct international financial assistance. FITs in *developed* countries have been successful in attracting private sector investments because of the secure and predictable cash flows they provide. Many developing country governments, international organizations, NGOs and international donors are therefore considering the option of internationally-supported FITs in *developing* countries to decouple their economic growth from greenhouse gas emissions.

However, given the long-term nature of the promised payments, designing internationally supported FIT mechanisms that provide the same level of investment security as in developed countries will be challenging. This article aimed to inform the discussion on how to design such a mechanism. It first reviewed and classified proposed mechanisms, before presenting a techno-economic analysis of a potential internationally supported FIT to assist Thailand's renewable energy targets for 2021.

Four main conclusions can be drawn from the analysis of the proposed mechanisms and the quantitative case study. First, the *magnitude* of the incremental cost of supported FITs is

[14] One way to approximate the marginal cost would be to link support to projected fossil fuel import prices [17], because these are typically more expensive and should therefore be the first to be replaced. However, how to design such a mechanism for countries with multiple import sources and multiple fossil fuels, such as Thailand, requires further investigation.

considerable. In the considered case of Thailand, the incremental cost of the FIT were estimated at USD 21bn, or 3.15% of Thailand's GDP in 2012. This magnitude of necessary commitments suggests that a global mechanism to channel financing to FITs in developing countries would have to be established outside the currently existing institutional landscape. The Green Climate Fund under the UNFCCC could be a suitable vehicle if the proposed USD 100bn per year from 2020 will indeed be raised from developed economies, but a long process of demonstration and institutional experimentation will surely be necessary to the build trust required before donors commit such large sums of money over decades.

Second, the incremental costs of supported FITs in developing countries are very *uncertain*. In the presented avoided cost scenarios for the case of Thailand, which all assume the same diffusion of renewable energy at the same *absolute cost* of energy, the *incremental cost* varied between −4.7% and +4.5% of Thailand's GDP in 2012. Because this uncertainty is only resolved over the lifetime of the FIT policy, which includes the lifetime of all supported projects, it implies further challenges for the design and implementation of a supported FIT: Donor countries will be unwilling to commit to financial assistance flows without knowing their eventual volume, while investors will only be attracted with a clear, long-term support commitment. Other options for international support for FITs in developing countries that do not envision the international side to directly cover part of the FIT payments, notably initiatives to reduce investment cost and investment risks e.g., [23], are not subject to this uncertainty. These options might therefore face fewer political and institutional challenges in the short term.

Third, the uncertainty in the incremental cost is driven, to a large extent, by the uncertain *savings from avoided fossil fuel consumption*. This is in part due to the absolute size of the avoided cost: In the case of Thailand, the incremental cost of the FIT were only 24% of the total FIT cost, because the avoided fossil fuel cost covered the remaining 76%. But it is also due to the nature of the uncertainty. Unlike the cost of the supported renewable electricity, which is also uncertain but can be managed by carefully designing the process in which commitments are made, the avoided cost uncertainty is resolved only over the life-time of the supported projects. Fuel prices may vary substantially over the 10–20 years that FIT payments have to be committed, and changes over time in the type of displaced electricity may result in large step changes in the avoided cost. In addition, the savings from the avoided fossil fuel consumption have to be determined through an analysis of the counterfactuals—i.e., by determining which power plants would have been built and which types of fuels consumed without the renewable installations. Arriving at a process to determine these counterfactuals that satisfies domestic governments and international donors will require much experimentation and policy learning.

Fourth, the reviewed proposals for internationally supported FITs differ in how they allocate the avoided cost uncertainty between national governments and international donors. Some proposals assign all cost uncertainty to the national government, whereas the international side assumes all uncertainty in others. Ideally, the avoided cost uncertainty would be allocated dependent on characteristics of the host country. While emerging middle-income countries can be expected to absorb this risk, international donors might be willing assume it when they support the least-developed countries. A support mechanism that differentiates the tariff payment structure depending on characteristics of the recipient country could thus be more suitable for large-scale support than a one-size-fits all approach.

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Appendix A

See Fig. A1 and Tables A1–A4.

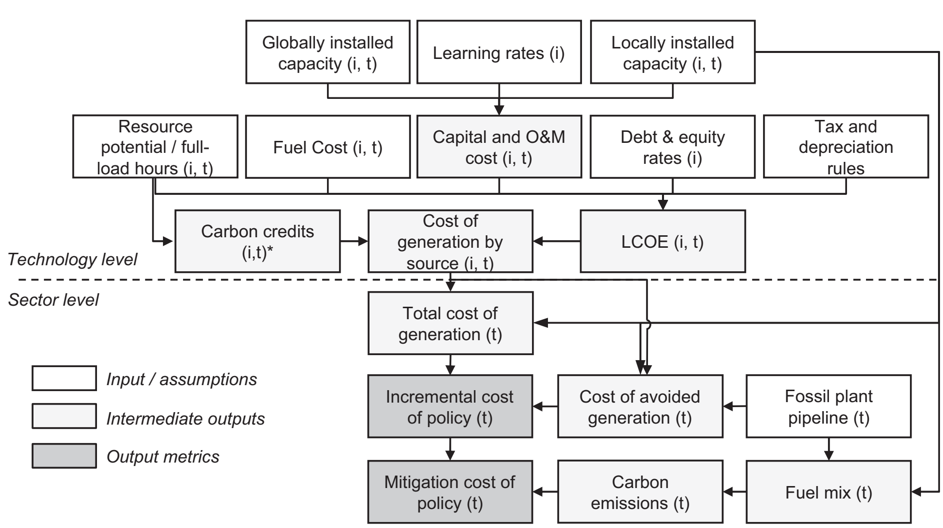

Fig. A1. Model structure: key relationships between input and output variables (function of technology *i*, year *t*) in the techno-economic model.

Table A1
Input assumptions for renewable energy technologies (values for 2012; in USD_{2012}).

	Size (MW)	Lifetime [a]	Investment[l] [USD/kW]	Learning rate	O&M fix [USD/kWa]	O&M variable [USD/MW h]	Fuel cost [USD/MW h]	Efficiency [%]	Capacity factor [%]	Dependable capacity [%]
Wind	10	20	1980[a]	4.3[j]	60[a]	0[a]	–	–	31.8[e]	9[f]
PV	10	20	2830[a]	20[j]	50[a]	0[a]	–	–	19.8[e]	20[f]
CSP	5	20	4910[a]	14.6[j]	50[a]	0[a]	–	–	21.5[e]	70[g]
Biomass	10	20	2157[b]	5[k]	0[b]	10.4[b]	41.2[b]	19.8%[b]	69[b]	55[g]
Biogas	1	20	2554[c]	5[k]	116[c]	0[c]	10[c]	31%[c]	70[c]	21[g]
Hydro	1	20	2800[d]	5[k]	112[d]	0[d]	–	–	29[i]	40[g]

[h]Munchareon et al. [69].

[a] NREL [65].
[b] Delivand et al. [50].
[c] Pattanapongchai and Limmeechokchai [66].
[d] IRENA [67].
[e] Calculated based on data from IRENA [53].
[f] Naksrisuk and Audomvongseree [68].
[g] Sangarasri-Greacen and Greacen [56].
[i] Promjiraprawat and Limmeechokchai [52].
[j] Hayward and Graham [70].
[k] Mott McDonald [71].
[l] The initial investment cost and the fixed O&M cost of each technology were assumed to decrease over time as a function of global cumulative installations and a fixed learning rate [72]. Global installation trends and values for 2011 were taken from IEA [73]; starting values for biomass and biogas from IRENA [74]; starting values for micro hydro from IRENA [75].

Table A2
Input assumptions for dispatchable fossil fuel technologies (values for 2012; in USD_{2012}).

	Lifetime [a]	Investment[g] [USD/kW]	O&M fixed [USD/kWa]	O&M variable [USD/MWh]	Fuel efficiency [%]	Fuel cost[h] [$cUSD/kWh_{th}$]	Capacity factor [%]	Carbon emissions [tCO_{2e}/MW h]
Subcritic. lignite	30	1125[a]	38.91[b]	11.02[b]	35[b]	0.54[d]	90	1,159[b]
IGCC lignite	30	2830[c]	50[c]	7.9[c]	46[c]	0.54[d]	90	882
Adv. nuclear	40	5429[c]	91.65[c]	2.1[c]	33[c]	0.31[d]	90	21[b]
Gas turbine	n/a	n/a	7.21[c]	15.28[c]	31.4[c]	2.49[e]	30	631[b]
CCGT	30	1006[c]	15.1[c]	3.21[c]	54[c]	2.49[e]	60	404[b]
Subcritic. coal	n/a	n/a	38[b]	0.04[b]	36[b]	1.39[f]	90	973[b]
Supercrit. coal	30	2934[c]	31.18[d]	4.7[d]	39[c]	1.39[f]	90	782[b]
IGCC coal	30	3784[c]	51.39[c]	8.45[c]	39[c]	1.39[f]	90	782[b]
Diesel turbine	n/a	n/a	12[a]	28.6[a]	22[a]	6.81[d]	30	808[b]

CCGT: combined cycle gas turbine; IGCC: integrated gasification combined cycle.

[a] Pattanapongchai and Limmeechokchai [66].
[b] Promjiraprawat and Limmeechokchai [52].
[c] DOE/EIA [76].
[d] EPPO [77].
[e] Price for natural gas is for imports from Myanmar, from PTIT [78].
[f] IEA [2].
[g] Investment cost and fixed O&M are assumed to decrease by 2.0% p.a.
[h] Fuel price reflect average natural gas prices, see Section 4.4; n/a: Not needed because no new power plants in the pipeline.

Table A3
Different pathways for natural gas prices 2010–2050 in Thailand. Starting values are taken from PTIT [78]; trend scenarios are adopted and extrapolated from IEA [57], and applied to the starting values.

Starting price	Trend scenario	2010	2015	2020	2025	2030	2035	2040	2045	2050
LNG import price	450°	6.95	7.52	7.58	7.58	7.64	7.64	7.64	7.64	7.64
	New policies	6.95	7.71	8.15	8.47	8.78	9.03	9.29	9.54	9.79
	Current policies	6.95	8.02	8.53	8.97	9.35	9.60	9.86	10.11	10.36
Average import price	450°	8.38	9.06	9.14	9.14	9.22	9.22	9.22	9.22	9.22
	New policies	8.38	9.29	9.83	10.21	10.59	10.89	11.20	11.50	11.81
	Current policies	8.38	9.67	10.28	10.82	11.27	11.58	11.88	12.19	12.49
Average price	450°	14.61	15.81	15.94	15.94	16.08	16.08	16.08	16.08	16.08
	New policies	14.61	16.21	17.14	17.80	18.47	19.00	19.53	20.06	20.59
	Current policies	14.61	16.87	17.94	18.87	19.66	20.19	20.73	21.26	21.79

Table A4
Sector-wide assumptions in the model.

Factor	Assumption	Source
Currency	USD 2012 in real terms	–
Exchange rate	1 USD=31.5 Thai Baht	The World Bank
Inflation	2.5%	Bank of Thailand
Equity/debt spilt	30/70	Current practice
Return on equity	11.2% real	UNFCCC [79]
Lending rate	6.7% nominal	Ondraczek et al. [80]
Loan tenor	Half of investment lifetime	Waissbein et al. [23]
Tax rate	30%	Current practice
Depreciation	Linear, max 5% p.a., min book value 5%	Current practice
Discounting of public expenditures	Equals 40-year bond yield of 4.43%	Thai bond market association[a]

[a] http://www.thaibma.or.th/yieldcurve/YieldTTM.aspx, assessed on 4/3/2014.

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